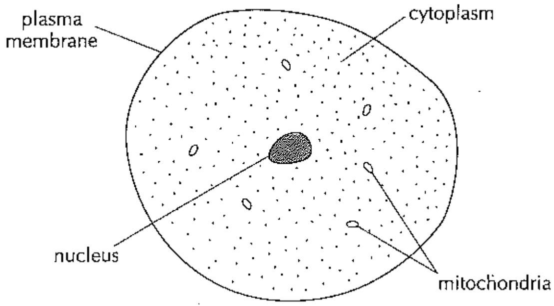
Cell theory

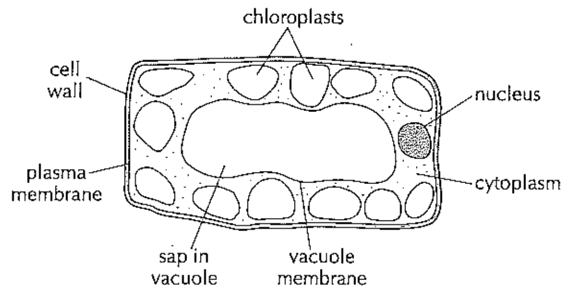
INTRODUCING CELLS

Cells consist of **cytoplasm**, enclosed in a **plasma membrane**, usually controlled by a single **nucleus**. Two cell types that can be easily looked at under a light microscope are human cheek cells, scraped from inside the mouth (left) and moss leaf cells (right).

Human cheek cell



Moss leaf cell

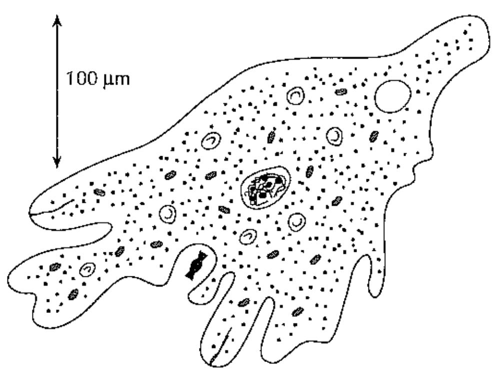


UNICELLULAR ORGANISMS

Some organisms such as *Amoeba* (below), *Chlorella* and *Euglena* have only one cell. This single cell has to carry out all the functions of life:

metabolism – chemical reactions inside the cell
response – reacting to stimuli
homeostasis – controlling conditions inside the cell
growth – increasing in size
reproduction – producing offspring
nutrition – obtaining food.

Amoeba



MULTICELLULAR ORGANISMS

Multicellular organisms consist of many cells. These cells do not have to carry out many different functions. Instead, they can become specialized for one particular function and carry it out very efficiently. Cells in a multicellular organism therefore develop in different ways. This is called **differentiation**. The way in which this occurs is described on page 4.

Multicellular organisms are said to show **emergent properties.** This means that the whole organism is more than the sum of its parts, because of the complex interactions between cells.

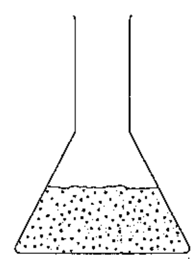
THE CELL THEORY

The cell theory includes these statements:

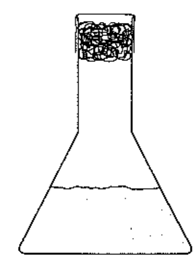
- living organisms are composed of cells
- cells are the smallest units of life
- cells come from pre-existing cells.

Many organisms have been examined and have been found to consist of cells, but there are some cases where the idea of living organisms consisting of tiny box-like structures does not seem to fit. For example, skeletal muscle is made up of **muscle fibres**. These are much larger than most cells (300 or more mm long) and contain hundreds of nuclei. Most fungi consist of thread-like structures called **hyphae**, which in some species contain many nuclei without dividing walls between. Many tissues, such as bone, contain a greater volume of **extracellular material** (material outside the cell membrane) than of cells. Despite these awkward cases, most living tissues are composed of cells. Also, whereas cells taken from an organism often survive for a time, smaller parts of an organism do not. Cells do therefore seem to be the smallest units of life that are capable of survival.

There is also evidence for the third part of the cell theory. Some of the classic experiments in biology showed that spontaneous generation of life is impossible (below). The first cells must have been formed in the origin of life from non-cellular material, but today there is no evidence that cells can be formed except by cell division.



Sterilized soup in an open container decays because bacteria float in



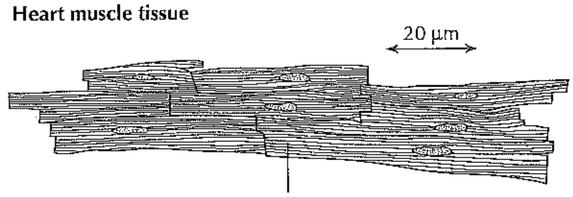
Sterilized soup in a sealed container does not decay as no bacteria are present

Stem cells and differentiation

DIFFERENTIATION

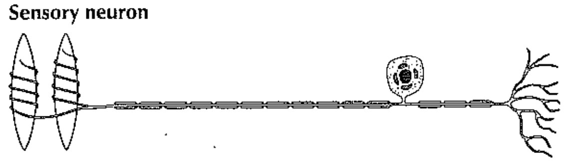
Cells in a multicellular organism develop in different ways and can therefore carry out different functions. This is called **differentiation**. The cells need different genes to develop in different ways. Each cell has all of these genes, so could develop in any way, but it only uses the ones that it needs to follow its pathway of development. Once a pathway of development has begun in a cell, it is usually fixed and the cell cannot change to follow a different pathway. The cell is said to be committed.
The drawings (below) show three of the hundreds of different types of differentiated cells in humans.

Heart muscle tissue

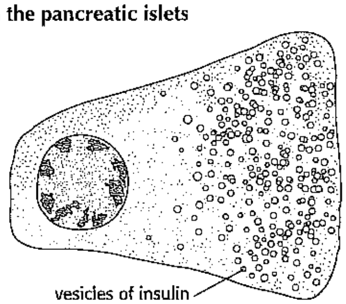


All heart muscle cells contain structures made from protein fibres that are used to contract the cell and help to pump blood in the heart.

Sensory neuron



Beta cell in the pancreatic islets



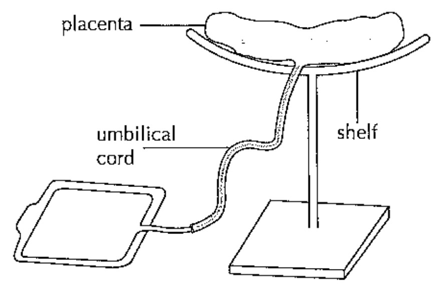
STEM CELLS

Stem cells are defined as cells that have the capacity to self-renew by cell division and to differentiate. Human embryos consist entirely of stem cells in their early stages, but gradually the cells in the embryo commit themselves to a pattern of differentiation. Once committed, a cell may still divide several more times, but all of the cells formed will differentiate in the same way and so they are no longer stem cells.
Small numbers of embryonic cells remain as stem cells however and they are still present in the adult body. They are found in most human tissues, including bone marrow, skin and liver. They give some human tissues considerable powers of regeneration and repair. The stem cells in other tissues only allow limited repair – brain, kidney and heart, for example.
There has been great interest in stem cells because of their potential for tissue repair and for treating a variety of degenerative conditions. For example, Parkinson's disease, multiple sclerosis and strokes all involve the loss of neurons or other cells in the nervous system. Although still only at the research stage, there is the potential to use stem cells to replace them.

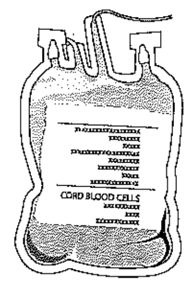
THERAPEUTIC USE OF STEM CELLS

In the future, many therapies may involve the use of stem cells. Some therapeutic uses have already been introduced. One example is given here.

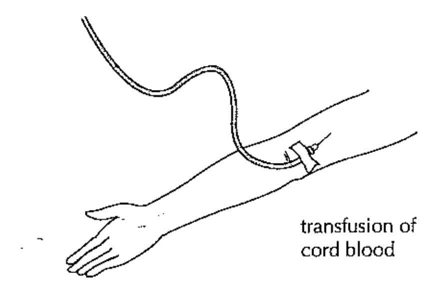
1. The placenta and umbilical cord of a baby is used as a source of stem cells. At the end of childbirth, the placenta is taken and placed on a stand, with the umbilical cord hanging down from it. Blood drains out of the umbilical cord and is collected – about 100cm^3. The cord blood contains many hematopoietic stem cells. These cells can divide and differentiate into any type of blood cell.



2. Red blood cells are removed from the cord blood and the remaining fluid is then tested to find its tissue type, check for disease-causing organisms and stored in liquid nitroge in a special bank of cord blood.



3. Cord blood can be used to treat patients, especially children, who have developed certain forms of leukemia. This is a cancer in which the cells in bone marrow divide uncontrollably, producing far too many white blood cells The patient's tissue type is matched with cord blood in th bank. If suitable cord blood is available, the patient is giv chemotherapy drugs that kill bone marrow cells, includir the cells causing the leukemia.



4. The selected cord blood is taken from the bank, thawed a introduced into the patient's blood system, usually via a v in the chest or arm. The hematopoietic stem cells establis themselves in the patient's bone marrow, where they divi repeatedly to build up a population of bone marrow cells replace those killed by the chemotherapy drugs.

Size in cell biology

LIMITATIONS TO CELL SIZE

Cells do not carry on growing indefinitely. They reach a maximum size and then may divide. If a cell became too large, it would develop problems because its surface area to volume ratio would become too small.

As the size of any object is increased, the ratio between the surface area and the volume decreases. Consider the surface area to volume ratio of cubes of varying size as an example.

The rate at which materials enter or leave a cell depends on the surface area of the cell. However, the rate at which materials are used or produced depends on the volume. A cell that becomes too large may not be able to take in essential materials or excrete waste substances quickly enough.

The same principle works for heat. Cells that generate heat may not be able to lose it quickly enough if they grow very large.

Surface area to volume ratios are important in biology. They help to explain many phenomena apart from maximum cell sizes.

UNITS FOR SIZE MEASUREMENTS

Most S.I. units differ from each other by a factor of 1000.

One millimetre is a thousand times smaller than 1 metre.

One micrometre is a thousand times smaller than 1 millimetre.

One nanometre is a thousand times smaller than 1 micrometre.

The most useful units for measuring the sizes of cells and structures within them are nanometres (nm) and micrometres (μm).

The typical sizes of some important structures in biology are shown opposite.

CALCULATING MAGNIFICATION

Photographs or drawings of structures seen under the microscope show them larger than they really are – they magnify them. It is useful to know how much larger the image is than the actual specimen. This factor is called the magnification. It is always helpful to show the magnification on a drawing of a biological structure.

Follow these instructions to calculate magnification.

1. Choose an obvious length, for example the maximum diameter of a cell. Measure it on the drawing.
2. Measure the same length on the actual specimen.
3. If the units used for the two measurements are different, convert one of them into the same units as the other one.
4. Divide the length on the drawing by the length on the actual specimen. The result is the magnification.

$$\text{Magnification} = \frac{\text{size of image}}{\text{size of specimen}}$$

This equation can also be used to calculate the actual size of a specimen if the magnification and size of the image are known.

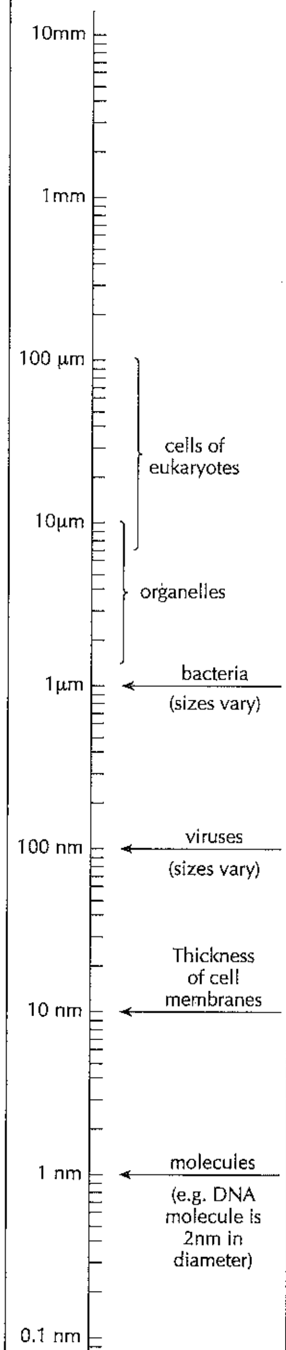
SCALE BARS

A scale bar is a line added to a micrograph or a drawing to help to show the actual size of the structures.

For example, a 10 μm bar shows how large a 10 μm object would appear.

The figure below shows is a scanning electron micrograph of a leaf with the magnification and a scale bar both shown.

Scanning electron micrograph of leaf (× 480)



1000 mm = 1 m

1000 μm = 1 mm

1000 nm = 1 μm

Prokaryotic cells

ULTRASTRUCTURE OF CELLS

From the 1950s onwards, cell structure could be studied in much greater detail than before, using electron microscopes. What was revealed is called the ultrastructure of the cell.

Cells were divided into two types according to their structure, **prokaryotic** and **eukaryotic**. The first cells to evolve were prokaryotic and many organisms still have prokaryotic cells, including all bacteria. These cells have no nucleus and the name prokaryotic means *before the nucleus.*

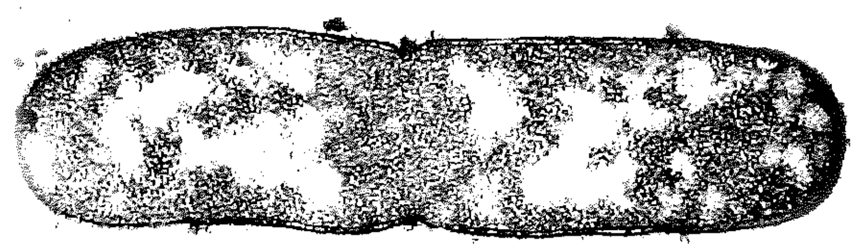
The functions of structures within prokaryotic cells are shown (right).

Prokaryotic cells divide in two by a process called **binary fission.**

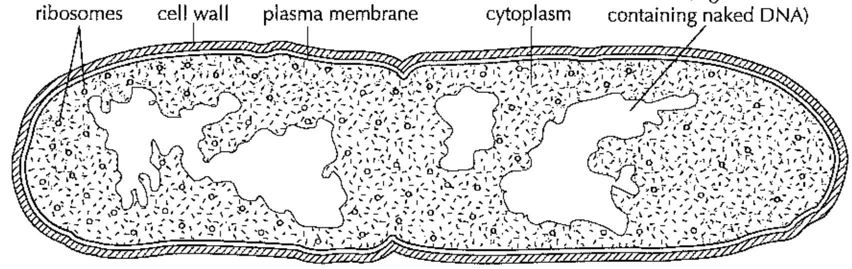
FUNCTIONS OF PARTS OF A PROKARYOTIC CELL

Structure	Function
Cell wall	Forms a protective outer layer that prevents damage from outside and also bursting if internal pressure is high.
Plasma membrane	Controls entry and exit of substances, pumping some of them in by active transport.
Cytoplasm	Contains enzymes that catalyse the chemical reactions of metabolism and contains DNA in a region called the nucleoid.
Pili	Hair-like structures projecting from the cell wall, that can be ratcheted in and out; when connected to another bacterial cell they can be used to pull cells together.
Flagella	Solid protein structures, with a corkscrew shape, projecting fron the cell wall, which rotate and cause locomotion.
Ribosomes	Small granular structures that synthesise proteins by translating messenger RNA. Some proteins stay in the cell and others are secreted.
Nucleoid	Region of the cytoplasm that contains naked DNA, which is the genetic information of the cell.

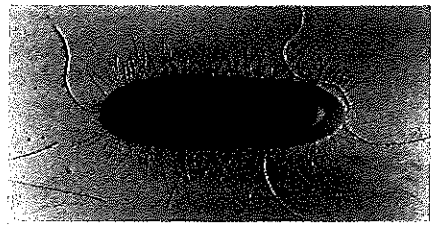
Electron micrograph of *Escherichia coli* (1–2 μm in length)

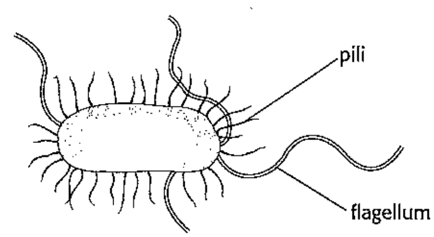


Drawing to help interpret the electron micrograph



Electron micrograph of *Escherichia coli* showing surface features



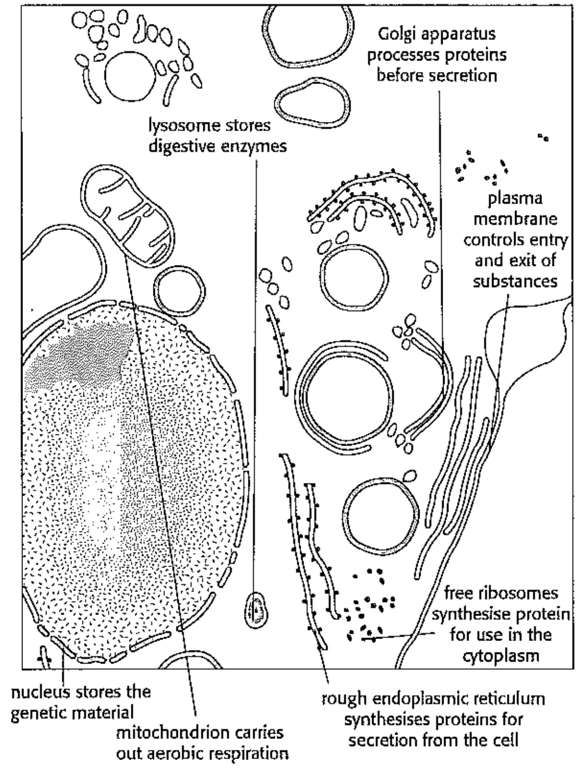


Eukaryotic cells

STRUCTURE OF A EUKARYOTIC CELL

Electron micrograph of a liver cell (× 6000)

Drawing to interpret parts of the electron micrograph



COMPARING PROKARYOTIC AND EUKARYOTIC CELLS

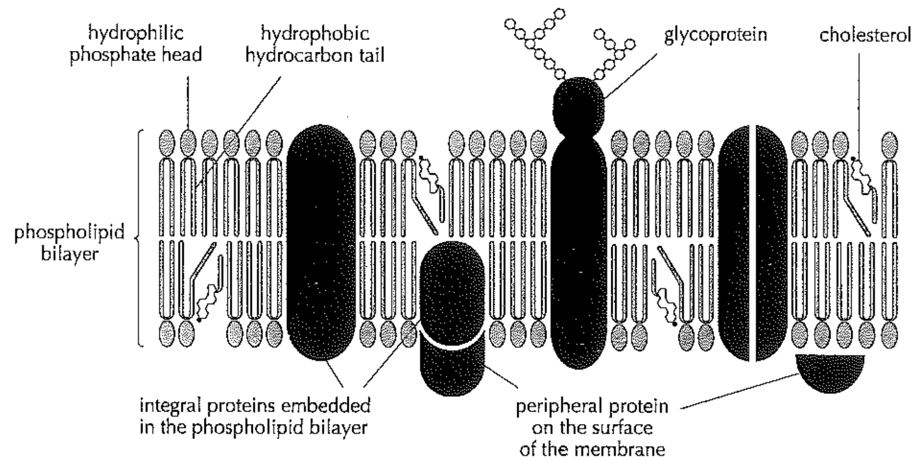
Feature	Prokaryotic cells	Eukaryotic cells
Type of genetic material	A naked loop of DNA	Chromosomes consisting of strands of DNA associated with protein. Four or more chromosomes are present.
Location of genetic material	In the cytoplasm in a region called the nucleoid	In the nucleus inside a double nuclear membrane called the nuclear envelope
Mitochondria	Not present	Always present
Ribosomes	Small sized – 70S	Larger sized – 80S
		(S = Svedberg units – related to the size of organelles)
Internal membranes	Few or none are present	Many internal membranes that compartmentalize the cytoplasm including ER, Golgi apparatuses, lysosomes

COMPARING PLANT AND ANIMAL CELLS

Feature	Animal	Plant
Cell wall	No cell wall, only a plasma membrane	Cell wall *and* plasma membrane present
Chloroplasts	Not present	Present in cells that photosynthesize
Polysaccharides	Glycogen is used as a storage compound	Starch is used as a storage compound
Vacuole	Not usually present	Large fluid-filled vacuole often present
Shape	Able to change shape. Usually rounded	Fixed shape. Usually rather regular

Membrane structure and membrane proteins

Fluid mosaic model of a biological membrane



PHOSPHOLIPIDS

Hydrophilic molecules are attracted to water. Hydrophobic molecules are not attracted to water, but are attracted to each other. Phospholipid molecules are unusual because they are partly hydrophilic and partly hydrophobic.

The phosphate head is hydrophilic and the two hydrocarbon tails are hydrophobic. In water, phospholipids form double layers with the hydrophilic heads in contact with water on both sides and the hydrophobic tails away from water in the centre. This arrangement is found in biological membranes. The attraction between the hydrophobic tails in the centre and between the hydrophilic heads and the surrounding water makes membranes very stable.

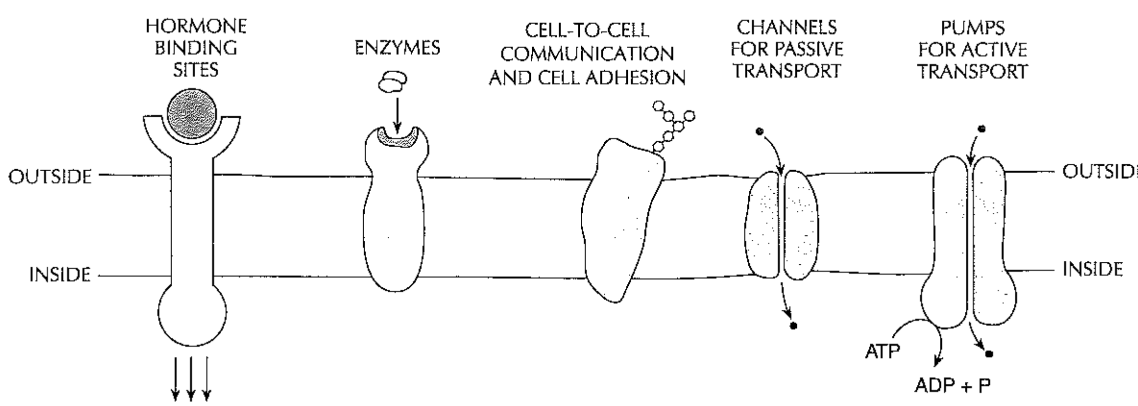
FLUIDITY OF MEMBRANES

Phospholipids in membranes are in a fluid state. This allows membranes to change shape in a way that would be impossible if they were solid. The fluidity also allows vesicles to be pinched off from membranes or fuse with them.

MEMBRANE PROTEINS

Some electron micrographs show the positions of proteins within membranes. The proteins are seen to be dotted over the membrane. This gives the membrane the appearance of a mosaic. Because the protein molecules float in the fluid phospholipid bilayer, biological membranes are called fluid mosaics. The figure (above) is a diagram showing the fluid mosaic model of a biological membrane. Some of the functions of membrane proteins are shown below.

Functions of membrane proteins



A site exposed on the outside of the membrane allows one specific hormone to bind. A signal is then transmitted to the inside of the cell

Enzymes located in membranes either catalyse reactions inside or outside the cell, depending on whether the active site is on the inner or outer surface

Glycoproteins in the membrane allow cells to communicate with each other and to stick together to form tissues

Channels are passages through the centre of membrane proteins. Each channel allows one specific substance to pass through

Pumps release energy from ATP and use it to move specific substances across the membrane

Passive transport across membranes

DIFFUSION

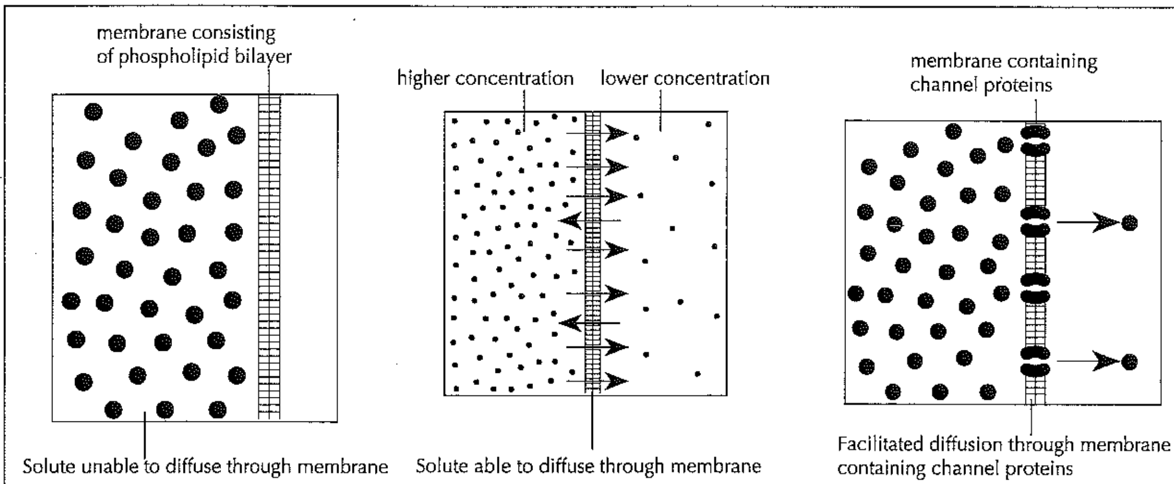
Solids, liquids and gases consist of particles – atoms, ions and molecules. In liquids and gases, these particles are in continual motion. The direction that they move in is random. If particles are evenly spread then their movement in all directions is even and there is no net movement – they remain evenly spread despite continually moving. Sometimes particles are unevenly spread – there is a higher concentration in one region than another. This causes diffusion.

Diffusion is the passive movement of particles from a region of higher concentration to a region of lower concentration, as a result of the random motion of particles.

Diffusion occurs because more particles move from the region of higher concentration to the region of lower concentration than move in the opposite direction. Diffusion can occur across membranes if there is a concentration gradient and if the membrane is permeable to the particle. For example, membranes are freely permeable to oxygen, so if there is a lower concentration of oxygen inside a cell than outside, it will diffuse into the cell. Membranes are not permeable to cellulose, so it does not diffuse across, even if there is a higher concentration on one side of a membrane than the other.

SIMPLE AND FACILITATED DIFFUSION

Membranes allow some substances to diffuse through but not others – they are **partially permeable.** Some of these substances move between the phospholipid molecules in the membrane – this is **simple diffusion.** Other substances are unable to pass between the phospholipids. To allow these substances to diffuse through membranes, channel proteins are needed. This is called **facilitated diffusion**. Channel proteins are specific – they only allow one type of substance to pass through. For example, chloride channels only allow chloride ions to pass through. Cells can control whether substances pass through their plasma membranes by facilitated diffusion, by the types of channel protein that are produced and inserted into the membrane. Cells cannot control the direction of movement. Facilitated diffusion always causes particles to move from a region of higher concentration to a region of lower concentration. Both simple and facilitated diffusion are passive processes – no energy has to be used by the cell to make them occur.
There are sodium and potassium channel proteins in the membranes of neurones that open and close, depending on the voltage across the membrane. They are called voltage-gated channels and are used during the transmission of nerve impulses.

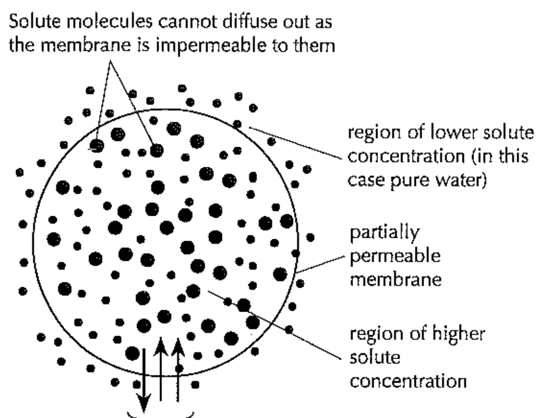


OSMOSIS

Plasma membranes are usually freely permeable to water. The passive movement of water across membranes is different from diffusion across membranes, because water is the solvent. A **solvent** is a liquid in which particles dissolve. Dissolved particles are called **solutes**. The direction in which water moves is due to the concentration of solutes, rather than the concentration of water molecules, so it is called osmosis, rather than diffusion.

Osmosis is the passive movement of water molecules from a region of lower solute concentration to a region of higher solute concentration, across a partially permeable membrane.

Attractions between solute particles and water molecules are the reason for water moving to regions with a higher solute concentration.

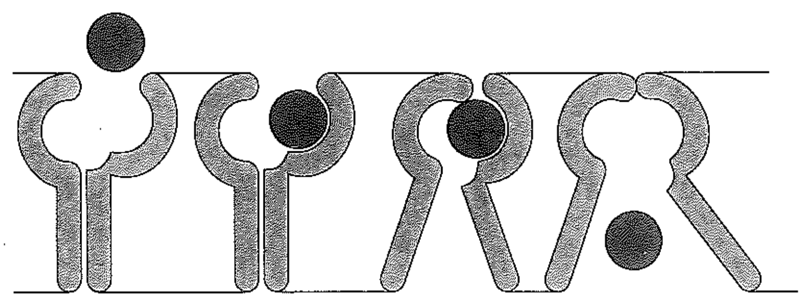


Water molecules move in and out through the membrane but more move in than out. There is a net movement from the region of lower solute concentration to the region of higher solute concentration

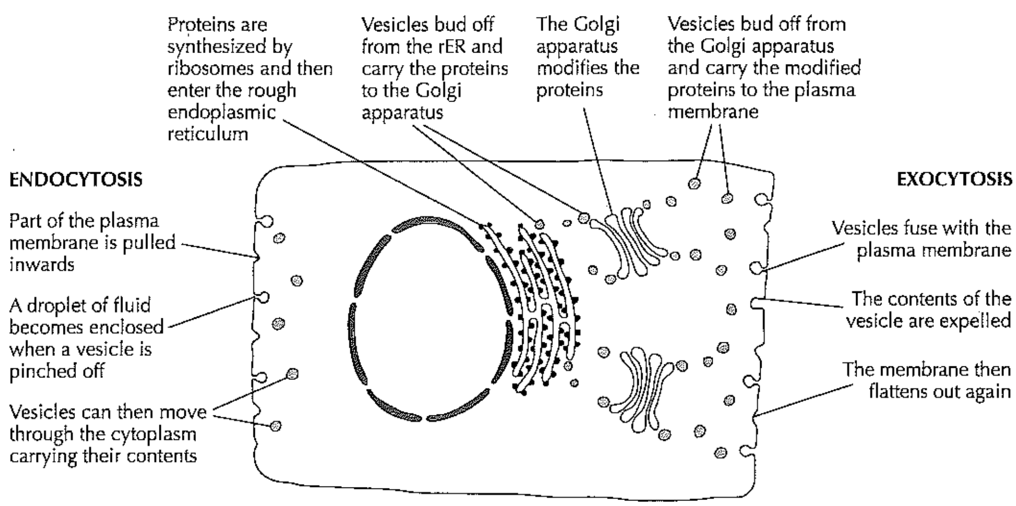
Active transport across membranes

PUMP PROTEINS AND ACTIVE TRANSPORT

Active transport is the movement of substances across membranes using energy from ATP. Active transport can move substances against the concentration gradient – from a region of lower to a region of higher concentration. Protein pumps in the membrane are used for active transport. Each pump only transports particular substances, so cells can control what is absorbed and what is expelled. Pumps work in a specific direction – the substance can only enter the pump on one side and can only exit on the other side.

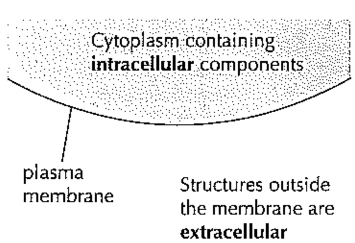


TRANSPORT OF MATERIALS BY VESICLES IN THE CYTOPLASM



EXTRACELLULAR COMPONENTS

The plasma membrane is the barrier that separates a cell from its surroundings. Cells sometimes produce components and then place them outside the plasma membrane, using exocytosis. These are called extracellular components. Two examples of the roles of extracellular components are outlined here:



1. **The plant cell wall**

Plants construct their cell walls by synthesising cellulose fibres in vesicles and adding them to the inner surface of the cell wall. Other substances are secreted to interconnect the cellulose fibres. The strength of the cellulose allows plant cell walls to have these roles:

- maintaining the cell's shape
- allowing high pressure to build up in the cell without it bursting
- high pressure in plant cells prevents excessive water uptake by osmosis
- high pressure in plant cells (turgor pressure) makes the cell almost rigid, helping to support the plant.

2. **Glycoproteins**

Many animal cells secrete glycoproteins, consisting of a protein to which carbohydrate is attached. This forms an extracellular matrix. Tissues that consist of a single layer of cells produce a thin layer of extracellular matrix called the basement membrane, for example around blood capillaries and around alveoli in the lungs. The matrix is a gel and has these roles:

- supporting single layers of thin cells, which might otherwise tear or perforate
- cell to cell adhesion, for example, a basement membrane helps capillary wall cells to adhere to alveolus wall cells.

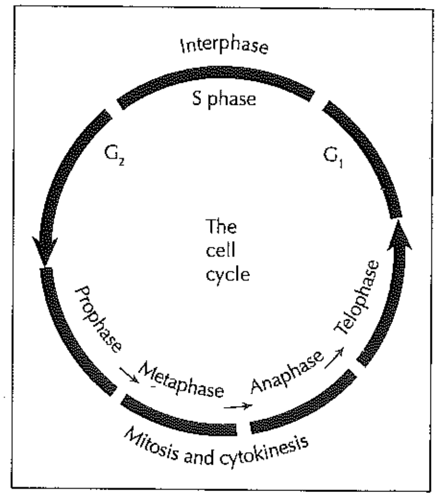
Cell division

THE CELL CYCLE IN EUKARYOTES

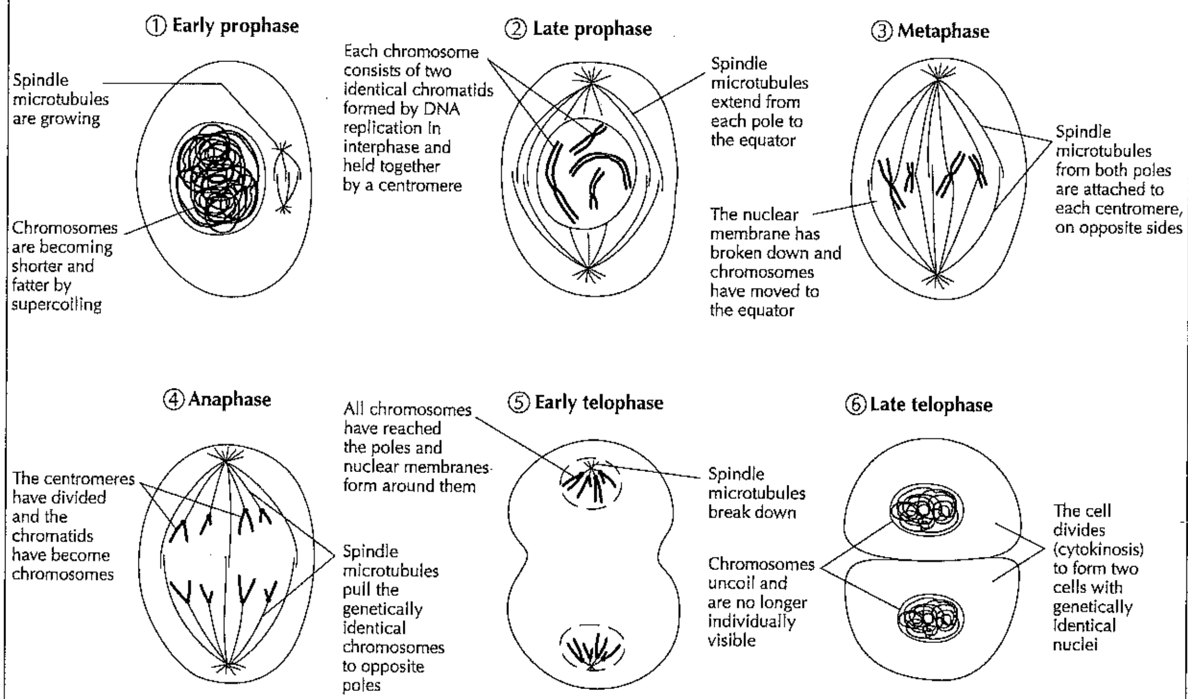
New cells are produced by division of existing cells. If many new cells are needed, cells go through a cycle of events again and again. This is called the cell cycle. The longest phase in this cycle is **interphase**. This is a very active period, during which the cell carries out many biochemical reactions and grows larger. The DNA molecules in the chromosomes are uncoiled and the genes on them can be transcribed, allowing the protein synthesis that is needed for growth. There is an increase in the number of mitochondria and in plant cells in the number of chloroplasts. There are three stages in interphase:

G_1 – a period of growth, DNA transcription and protein synthesis
S phase – the period during which all DNA in the nucleus is replicated
G_2 – a period in which the cell prepares for division.

At the end of interphase, the cell begins **mitosis** – the process by which the nucleus divides to form two genetically identical nuclei. Towards the end of mitosis, the cytoplasm of the cell starts to divide and eventually two cells are formed, each containing one nucleus. The process of dividing the cytoplasm to form two cells is **cytokinesis**. The two cells begin interphase when mitosis and cytokinesis have been completed.



THE PHASES OF MITOSIS



USES OF MITOSIS

Mitosis is used in eukaryotes whenever genetically identical cells are needed:

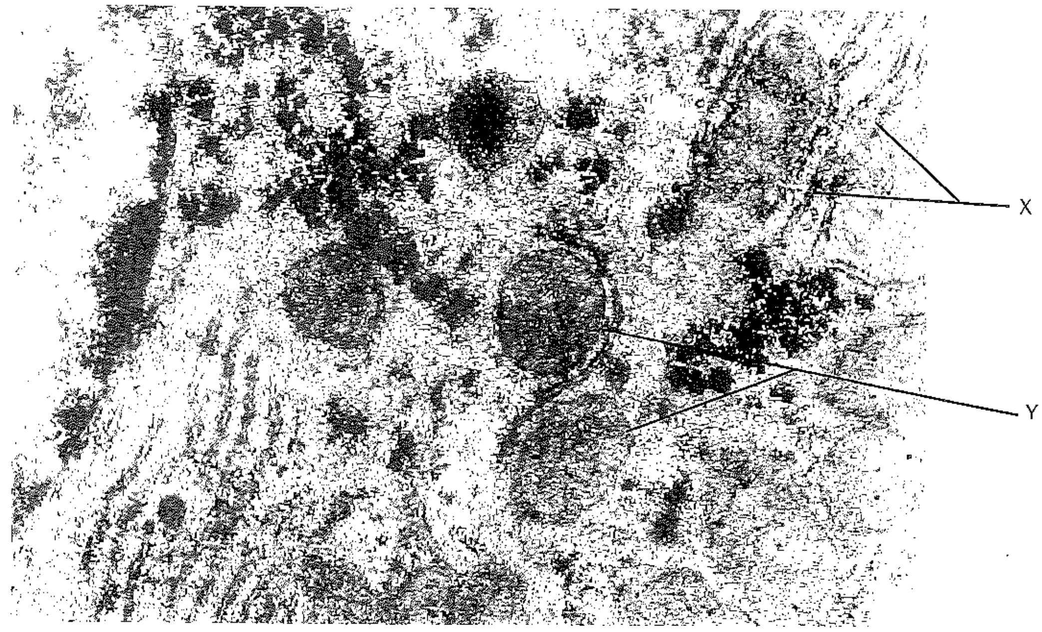
- during growth
- during embryonic development, when the large cell produced by fertilization (zygote) divides repeatedly to produce many smaller cells
- when tissues have been damaged and need to be repaired
- to reproduce asexually.

TUMOUR FORMATION

Sometimes the normal control of mitosis in a cell fails, due to a change in the genes of the cell. This cell divides into two, which inherit the change in the genes. The two daughter cells divide to form four cells. Repeated uncontrolled divisions soon produce a mass of cells called a tumour. This can happen in any tissue and in any organ. Tumours can grow to a large size and can spread to other parts of the body. The diseases caused by the growth of tumours are called cancer.

EXAM QUESTIONS ON TOPICS 1 AND 2

1 The photomicrograph below shows a transverse section of part of a liver cell.



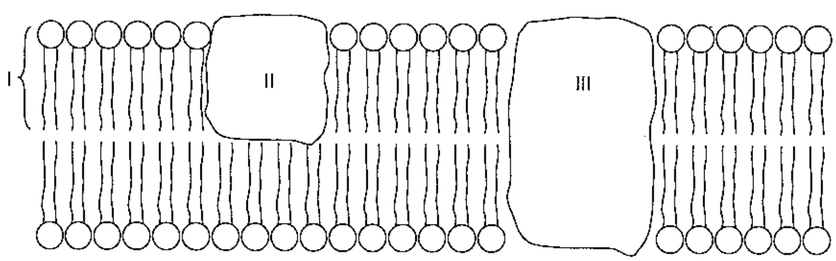
a) Identify the organelles labelled X and Y. [2]

b) On the photomicrograph, identify the nuclear membrane and show its position with a clear label. [1]

c) The liver cell shown in the photomicrograph was making large amounts of two substances.

Deduce what the two substances were, giving reasons for your answer based on the organelles visible in the photomicrograph. [2]

2 The diagram below represents the fluid model of a cell membrane.



a) (i) State the name of the molecule labelled I. [1]

(ii) Label the diagram to show which part of molecule I is hydrophobic and which part is hydrophilic. [1]

b) (i) Identify whether molecule II is an integral or a peripheral protein. [1]

(ii) Describe the part played by molecule III in active transport. [2]

3 Ten teenage boys, aged 17 or 18, estimated their body fat percentage by measurements of skin fold thickness.

The estimates (%) were: 25.6, 12.9, 8.1, 10.2, 10.0, 8.9, 8.1, 15.3, 11.2, 13.7.

a) (i) Calculate the mean estimated body fat percentage. [2]

(ii) Calculate the standard deviation. [2]

The boys also measured their blood pressure. The boys whose estimated body fat percentages were higher tended to have higher blood pressure.

b) (i) What is this type of relationship between two variables called? [2]

(ii) Discuss whether this relationship proves that becoming obese causes high blood pressure. [2]